LOW RESISTANCE POLYMER MATRIX FUSE APPARATUS AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part application of U.S. Application Serial No. 10/339,114 filed January 9, 2003, which claims the benefit of Provisional Application Serial No. 60/348,098 filed January 10, 2002.

BACKGROUND OF THE INVENTION

[0002] This invention relates generally to fuses, and, more particularly, to fuses employing foil fuse elements.

[0003] Fuses are widely used as overcurrent protection devices to prevent costly damage to electrical circuits. Typically, fuse terminals or contacts form an electrical connection between an electrical power source and an electrical component or a combination of components arranged in an electrical circuit. One or more fusible links or elements, or a fuse element assembly, is connected between the fuse terminals or contacts, so that when electrical current through the fuse exceeds a predetermined threshold, the fusible elements melt, disintegrate, sever, or otherwise open the circuit associated with the fuse to prevent electrical component damage.

[0004] A proliferation of electronic devices in recent times has resulted in increased demands on fusing technology. For example, a conventional fuse includes a wire fuse element (or alternatively a stamped and/or shaped metal fuse element) encased in a glass cylinder or tube and suspended in air within the tube. The fuse element extends between conductive end caps attached to the tube for connection to an electrical circuit. However, when used with printed circuit boards in electronic applications, the fuses typically must be quite small, leading to manufacturing and installation difficulties for these types of fuses that increase manufacturing and assembly costs of the fused product.

[0005] Other types of fuses include a deposited metallization on a high temperature organic dielectric substrate (e.g. FR-4, phenolic or other polymer-based material) to form a fuse element for electronic applications. The fuse element may be vapor deposited, screen printed, electroplated or applied to the substrate using known techniques, and fuse element geometry may be varied by chemically etching or laser trimming the metallized layer forming the fuse element. However, during an overcurrent condition, these types of fuses tend to conduct heat from the fuse element into the substrate, thereby increasing a current rating of the fuse but also increasing electrical resistance of the fuse, which may undesirably affect low voltage electronic circuits. In addition, carbon tracking may occur when the fuse element is in close proximity to or is deposited directly on a dielectric substrate. Carbon tracking will not allow the fuse to fully clear or open the circuit as the fuse was intended.

[0006] Still other fuses employ a ceramic substrate with a printed thick film conductive material, such as a conductive ink, forming a shaped fuse element and conductive pads for connection to an electrical circuit. However, inability to control printing thickness and geometry can lead to unacceptable variation in fused devices. Also, the conductive material that forms the fuse element typically is fired at high temperatures so a high temperature ceramic substrate must be used. These substrates, however, tend to function as a heat sink in an overcurrent condition, drawing heat away from the fuse element and increasing electrical resistance of the fuse.

[0007] In many circuits high fuse resistance is detrimental to the functioning of active circuit components, and in certain applications voltage effects due to fuse resistance may render active circuit components inoperable.

BRIEF DESCRIPTION OF THE INVENTION

[0008] In accordance with an exemplary embodiment, a low resistance fuse is provided. The fuse comprises a polymer membrane, a fuse element layer formed on the polymer membrane, and first and second intermediate insulation layers extending on opposite sides of the fuse element layer and coupled thereto. At

least one of the first and second intermediate insulation layers comprises an opening therethrough, and the polymer membrane supports the fuse element layer in the opening.

[0009] In another exemplary embodiment, a method of fabricating a low resistance fuse is provided. The method comprises providing a first intermediate insulating layer, forming a fuse element layer having a fusible link extending between first and second contact pads, and adhesively laminating a second intermediate insulation layer to the first intermediate insulating layer over the fuse element layer.

[0010] In another exemplary embodiment, a low resistance fuse is provided. The fuse comprises a thin foil fuse element layer, and first and second intermediate insulation layers extending on opposite sides of the fuse element layer and coupled thereto. The fuse element layer is formed on the first intermediate insulation layer and the second insulation layer is laminated to the fuse element layer. At least one of the first and second intermediate insulation layers comprises an opening therethrough, and an arc quenching media is located within the opening and surrounds the fuse element layer within the opening.

[0011] In another exemplary embodiment, a low resistance fuse comprises a thin foil fuse element layer, and first and second intermediate insulation layers extending on opposite sides of the fuse element layer and coupled thereto. The fuse element layer is formed on the first intermediate insulation layer and the second insulation layer is laminated to the fuse element layer. At least one of the first and second intermediate insulation layers comprises an opening therethrough; and a heat sink is coupled to one of the first and second intermediate insulating layers.

[0012] In another exemplary embodiment, a low resistance fuse is provided. The fuse comprises a thin foil fuse element layer, and first and second intermediate insulation layers extending on opposite sides of the fuse element layer and coupled thereto. The fuse element layer is formed on the first intermediate insulation layer and the second insulation layer laminated to the fuse element layer. At least one of the first and second intermediate insulation layers comprises an

opening therethrough, and a heat sink is coupled to one of the first and second intermediate insulating layers.

[0013] In still another exemplary embodiment, a low resistance fuse is provided. The fuse comprises a thin foil fuse element layer, and first and second intermediate insulation layers extending on opposite sides of the fuse element layer and coupled thereto. The fuse element layer is formed on the first intermediate insulation layer and the second insulation layer is laminated to the fuse element layer, wherein at least one of the first and second intermediate insulation layers comprises an opening therethrough. First and second outer insulation layers are laminated to the first and second intermediate insulation layers, wherein the fuse element layer and the opening are configured to model an adiabatic envelope around a portion of the fuse element layer in a vicinity of the opening.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Figure 1 is a perspective view of a foil fuse.

[0015] Figure 2 is an exploded perspective view of the fuse shown in Figure 1.

[0016] Figure 3 is a process flow chart of a method of manufacturing the fuse shown in Figures 1 and 2.

[0017] Figure 4 is an exploded perspective view of a second embodiment of a foil fuse.

[0018] Figure 5 is an exploded perspective view of a third embodiment of a foil fuse.

[0019] Figures 6-10 are top plan views of fuse element geometries for the fuses shown in Figures 1-5.

[0020] Figure 10 is an exploded perspective view of a fourth embodiment of a fuse.

[0021] Figure 12 is process flow chart of a method of manufacturing the fuse shown in Figure 11.

[0022] Figure 13 is a perspective view of a fifth embodiment of a fuse.

[0023] Figure 14 is an exploded view of the fuse shown in Figure 12.

[0024] Figure 15 is an exploded view of a sixth embodiment of a fuse.

[0025] Figure 16 an exploded view of a seventh embodiment of a fuse.

[0026] Figure 17 is a schematic view of an eighth embodiment of a fuse.

[0027] Figure 18 is a top plan view of one embodiment of a fuse element.

[0028] Figure 19 is a top plan view of another embodiment of a fuse element.

[0029] Figure 20 is an exploded view of a fuse manufacture.

DETAILED DESCRIPTION OF THE INVENTION

[0030] Figure 1 is a perspective view of a foil fuse 10 in accordance with an exemplary embodiment of the present invention. For the reasons set forth below, fuse 10 is believed to be manufacturable at a lower cost than conventional fuses while providing notable performance advantages. For example, fuse 10 is believed to have a reduced resistance in relation to known comparable fuses and increased insulation resistance after the fuse has operated. These advantages are achieved at least in part through the use of thin metal foil materials for formation of a fusible link and contact terminations mounted onto polymer films. For descriptive purposes herein, thin metal foil materials are deemed to range in thickness from about

1 to about 100 microns, more specifically from about 1 to about 20 microns, and in a particular embodiment from about 3 to about 12 microns.

[0031] While at least one fuse according to the present invention has been found particularly advantageous when fabricated with thin metal foil materials, it is contemplated that other metallization techniques may also be beneficial. For example, for lower fuse ratings that require less than 3 to 5 microns of metallization to form the fuse element, thin film materials may be used according to techniques known in the art, including but not limited to sputtered metal films. It is further appreciated that aspects of the present invention may also apply to electroless metal plating constructions and to thick film screen printed constructions. Fuse 10 is therefore described for illustrative purposes only, and the description of fuse 10 herein is not intended to limit aspects of the invention to the particulars of fuse 10.

[0032] Fuse 10 is of a layered construction, described in detail below, and includes a foil fuse element (not shown in Figure 1) electrically extending between and in a conductive relationship with solder contacts 12 (sometimes referred to as solder bumps). Solder contacts 12, in use, are coupled to terminals, contact pads, or circuit terminations of a printed circuit board (not shown) to establish an electrical circuit through fuse 10, or more specifically through the fuse element. When current flowing through fuse 10 reaches unacceptable limits, dependant upon characteristics of the fuse element and particular materials employed in manufacture of fuse 10, the fuse element melts, vaporizes, or otherwise opens the electrical circuit through the fuse and prevents costly damage to electrical components in the circuit associated with fuse 10.

[0033] In an illustrative embodiment, fuse 10 is generally rectangular in shape and includes a width W, a length L and a height H suitable for surface mounting of fuse 10 to a printed circuit board while occupying a small space. For example, in one particular embodiment, L is approximately 0.060 inches and W is approximately 0.030 inches, and H is considerably less than either L or W to maintain a low profile of fuse 10. As will become evident below, H is approximately equal to the combined thickness of the various layers employed to fabricate fuse 10. It is

recognized, however, that actual dimensions of fuse 10 may vary from the illustrative dimensions set forth herein to greater or lesser dimensions, including dimensions of more than one inch without departing from the scope of the present invention.

[0034] It is also recognized that at least some of the benefits of the present invention may be achieved by employing other fuse terminations than the illustrated solder contacts 12 for connecting fuse 10 to an electrical circuit. Thus, for example, contact leads (i.e. wire terminations), wrap-around terminations, dipped metallization terminations, plated terminations, castellated contacts, and other known connection schemes may be employed as an alternative to solder contacts 12 as needs dictate or as desired.

[0035] Figure 2 is an exploded perspective view of fuse 10 illustrating the various layers employed in fabrication of fuse 10. Specifically, in an exemplary embodiment, fuse 10 is constructed essentially from five layers including a foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 26, 28.

[0036] Foil fuse element layer 20, in one embodiment, is an electro deposited, 3-5 micron thick copper foil applied to lower intermediate layer 24 according to known techniques. In an exemplary embodiment, the foil is a CopperBond® Extra Thin Foil available from Olin, Inc., and thin fuse element layer 20 is formed in the shape of a capital I with a narrowed fusible link 30 extending between rectangular contact pads 32, 34. Fusible link 30 is dimensioned to open when current flowing through fusible link 30 reaches a specified level. For example, in an exemplary embodiment, fusible link 30 is about 0.003 inches wide so that the fuse operates at less than 1 ampere. It is understood, however, that in alternative embodiments various dimensions of the fusible link may be employed and that thin fuse element layer 20 may be formed from other metal foils, including but not limited to nickel, zinc, tin, aluminum, silver, alloys thereof (e.g., copper/tin, silver/tin, and copper/silver alloys) and other conductive foil materials in lieu of a copper foil. In alternative embodiments, 9 micron or 12 micron thickness foil materials may be

employed and chemically etched to reduce the thickness of the fusible link. Additionally, a known M-effect fusing technique may be employed in further embodiments to enhance operation of the fusible link.

[0037] As appreciated by those in the art, performance of the fusible link (e.g. short circuit performance and interrupting voltage capability) is dependant upon and primarily determined by the melting temperature of the materials used and the geometry of the fusible link, and through variation of each a virtually unlimited number of fusible links having different performance characteristics may be obtained. In addition, more than one fusible link may extend in parallel to further vary fuse performance. In such an embodiment, multiple fusible links may extend in parallel between contact pads in a single fuse element layer or multiple fuse element layers may be employed including fusible links extending parallel to one another in a vertically stacked configuration.

[0038] To select materials to produce a fuse element layer 20 having a desired fuse element rating, or to determine a fuse element rating fabricated from selected materials, it has been determined that fusing performance is primarily dependant upon three parameters, including fuse element geometry, thermal conductivity of the materials surrounding the fuse element, and a melting temperature of the fusing metal. It has been determined that each of these parameters are directly proportionate to arcing time when the fuse operates, and in combination each of these parameters determine the time versus current characteristics of the fuse. Thus, through careful selection of materials for the fuse element layer, materials surrounding the fuse element layer, and geometry of the fuse element layer, acceptable low resistance fuses may be produced.

[0039] Considering first the geometry of fuse element 20, for purposes of illustration the characteristics of an exemplary fuse element layer will be analyzed. For example, Figure 6 illustrates a plan view of a relatively simple fuse element geometry including exemplary dimensions.

[0040] Referring to Figure 6, a fuse element layer in the general shape of a capital I is formed on an insulating layer. Fusing characteristics of the fuse element layer are governed by the electrical conductivity (ρ) of the metal used to form fuse element layer, dimensional aspects of the fuse element layer (i.e., length and width of fuse element) and the thickness of the fuse element layer. In an illustrative embodiment, the fuse element layer 20 is formed from a 3 micron thick copper foil, which is known to have a sheet resistance (measured for a 1 micron thickness) of $1/\rho$*cm or about $0.16779\Omega/\square$ where $\square$ is a dimensional ratio of the fuse element portion under consideration expressed in "squares."

[0041] For example, considering the fuse element shown in Figure 6, the fuse element includes three distinct segments identifiable with dimensions l_1 and w_1 corresponding to the first segment, l_2 and w_2 corresponding to the second segment and l_3 and w_3 corresponding to the third segment. By summing the squares in the segments the resistivity of the fuse element layer may approximately determined in a rather direct manner. Thus, for the fuse element shown in Figure 6:

$$Number of\ squares = \left({}^{l_1}\!/_{w_1} + {}^{l_2}\!/_{w_2} + {}^{l_3}\!/_{w_3} \right) \qquad (1)$$

$$= \left({}^{10}\!/_{20} + {}^{30}\!/_{4} + {}^{10}\!/_{20} \right)$$

$$= 8.5\ \square\text{'s}.$$

Now the electrical resistance (R) of the fuse element layer may be determined according to the following relationship:

$$\text{Fuse Element R} = \text{(Sheet Resistivity)*(Number } \square\text{'s)/T} \qquad (2)$$

where T is a thickness of the fuse element layer. Continuing with the foregoing example and applying Equation (2), it may be seen that:

$$\text{Fuse Element Resistance} = (0.16779\Omega/\square)*(8.5\ \square)/3$$

$$= 0.0475\ \Omega.$$

Of course, a fuse element resistance of a more complicated geometry could be likewise determined in a similar fashion.

[0042] Considering now the thermal conductivity of materials surrounding the fuse element layer, those in the art may appreciate that heat flow (H) between subvolumes of dissimilar material is governed by the relationship:

$$\Delta h_{(m,n)\ to\ (m+1,n)} = \frac{2(\theta_{m,n} - \theta) * Y_n * Z * K_{m,n} * \Delta t}{X_{m,n}} \quad (3)$$

where $K_{m,n}$ is a thermal conductivity of a first subvolume of material; $K_{m+1,n}$ is a thermal conductivity of second subvolume of material; Z is a thickness of the material at issue; θ is the temperature of subvolume m,n at a selected reference point; $X_{m,n}$ is a first coordinate location of the first subvolume measure from the reference point, and Y_n is a second coordinate location measure from the reference point, and Δt is a time value of interest.

[0043] While Equation (3) may be studied in great detail to determine precise heat flow characteristics of a layered fuse construction, it is presented herein primarily to show that heat flow within the fuse is proportional to the thermal conductivity of the materials used. Thermal conductivity of some exemplary known materials are set forth in the following Table, and it may be seen that by reducing the conductivity of the insulating layers employed in the fuse around the fuse element, heat flow within the fuse may be considerably reduced. Of particular note is the significantly lower conductivity of polyimide, which is employed in illustrative embodiments of the invention as insulating material above and below the fuse element layer.

Substrate Thermal Conductivity's (W/mK)

Alumina (Al_2O_3)	19
Forsterite ($2MgO-SiO_2$)	7
Cordierite ($2MgO-2Al_2O_3-5SiO_2$)	1.3
Steatite ($2MgO-SiO_2$)	3
Polyimide	0.12
FR-4 Epoxy Resin/Fiberglass Laminate	0.293

[0044] Now considering the operating temperature of the fusing metal employed in fabrication of the fuse element layer, those in the art may appreciate that the operating temperature θ_t of the fuse element layer at a given point in time is governed by the following relationship:

$$\theta_t = \left(1/_{m * s}\right) * \int i^2 R_{am}(1+\alpha\theta)dt \qquad (4)$$

where m is the mass of the fuse element layer, s is the specific heat of the material forming the fuse element layer, R_{am} is the resistance of the fuse element layer at an ambient reference temperature θ, i is a current flowing through the fuse element layer, and α is a resistance temperature coefficient for the fuse element material. Of course, the fuse element layer is functional to complete a circuit through the fuse up to the melting temperature of the fuse element material. Exemplary melting points of commonly used fuse element materials are set forth in the table below, and is noted that copper fuse element layers are especially advantageous in the present invention due to the significantly higher melting temperature of copper which permits higher current rating of the fuse element.

Metal and Metal Alloy Melt Temperatures (°C)

Copper (Cu)	1084
Zinc (Zn)	419
Aluminum (Al)	660
Copper/Tin (20Cu/80Sn)	530
Silver/Tin (40Ag/60Sn)	450
Copper/Silver (30Cu/70Ag)	788

[0045] It should now be evident that consideration of the combined effects of melting temperature of materials for the fuse element layer, thermal conductivity of materials surrounding the fuse element layer, and the resistivity of the of the fuse element layer, acceptable low resistance fuses may be produced having a variety of performance characteristics.

[0046] Referring back to Figure 2, upper intermediate insulating layer 22 overlies foil fuse element layer 20 and includes rectangular termination openings 36, 38 or windows extending therethrough to facilitate electrical connection to respective contact pads 32, 34 of foil fuse element layer 20. A circular shaped fusible link opening 40 extends between termination openings 36, 38 and overlies fusible link 30 of foil fuse element layer 20.

[0047] Lower intermediate insulating layer 24 underlies foil fuse element layer 20 and includes a circular shaped fuse link opening 42 underlying fusible link 30 of foil fuse element layer 20. As such, fusible link 30 extends across respective fuse link openings 40, 42 in upper and lower intermediate insulating layers 22, 24 such that fusible link 30 contacts a surface of neither intermediate insulating layer 22, 24 as fusible link 30 extends between contact pads 32, 34 of foil fuse element 20. In other words, when fuse 10 is fully fabricated, fusible link 30 is

effectively suspended in an air pocket by virtue of fuse link openings 40, 42 in respective intermediate insulating layers 22, 24.

[0048] As such, fuse link openings 40, 42 prevent heat transfer to intermediate insulating layers 22, 24 that in conventional fuses contributes to increased electrical resistance of the fuse. Fuse 10 therefore operates at a lower resistance than known fuses and consequently is less of a circuit perturbation than known comparable fuses. In addition, and unlike known fuses, the air pocket created by fusible link openings 40, 42 inhibits arc tracking and facilitates complete clearing of the circuit through fusible link 30. In a further embodiment, a properly shaped air pocket may facilitate venting of gases therein when the fusible link operates and alleviate undesirable gas buildup and pressure internal to the fuse. Thus, while openings 40, 42 are illustrated as substantially circular in an exemplary embodiment, non-circular openings 40, 42 may likewise be employed without departing from the scope and spirit of the present invention. Additionally, it is contemplated that asymmetrical openings may be employed as fuse link openings in intermediate insulating layers 22, 24. Still further, it is contemplated that the fuse link openings, however, may be filled with a solid or gas to inhibit arc tracking in lieu of or in addition to air as described above.

[0049] In an illustrative embodiment, upper and lower intermediate insulation layers are each fabricated from a dielectric film, such as a 0.002 inch thick polyimide commercially available and sold under the trademark KAPTON® from E. I. du Pont de Nemours and Company of Wilmington, Delaware. It is appreciated, however, that in alternative embodiments, other suitable electrical insulation materials (polyimide and non-polyimide) such as CIRLEX® adhesiveless polyimide lamination materials, UPILEX® polyimide materials commercially available from Ube Industries, Pyrolux, polyethylene naphthalendicarboxylate (sometimes referred to as PEN), Zyvrex liquid crystal polymer material commercially available from Rogers Corporation, and the like may be employed in lieu of KAPTON®.

[0050] Upper outer insulation layer 26 overlies upper intermediate layer 22 and includes rectangular termination openings 46, 48 substantially coinciding

with termination openings 36, 38 of upper intermediate insulation layer 22. Together, termination openings 46, 48 in upper outer insulating layer 26 and termination openings 36, 38 in upper intermediate insulating layer 22 form respective cavities above thin fuse element contact pads 32, 34. When openings 36, 38, 46, 48 are filled with solder (not shown in Figure 2), solder contact pads 12 (shown in Figure 1) are formed in a conductive relationship to fuse element contact pads 32, 34 for connection to an external circuit on, for example, a printed circuit board. A continuous surface 50 extends between termination openings 46, 48 of upper outer insulating layer 26 that overlies fusible link opening 40 of upper intermediate insulating layer 22, thereby enclosing and adequately insulating fusible link 30.

[0051] In a further embodiment, upper outer insulation layer 26 and/or lower outer insulation layer 28 is fabricated from translucent or transparent materials that facilitate visual indication of an opened fuse within fusible link openings 40, 42.

[0052] Lower outer insulating layer 28 underlies lower intermediate insulating layer 24 and is solid, i.e., has no openings. The continuous solid surface of lower outer insulating layer 24 therefore adequately insulates fusible link 30 beneath fusible link opening 42 of lower intermediate insulating layer 28.

[0053] In an illustrative embodiment, upper and lower outer insulation layers are each fabricated from a dielectric film, such as a 0.005 inch thick polyimide film commercially available and sold under the mark KAPTON® from E. I. du Pont de Nemours and Company of Wilmington, Delaware. It is appreciated, however, that in alternative embodiments, other suitable electrical insulation materials such as CIRLEX® adhesiveless polyimide lamination materials, Pyrolux, polyethylene naphthalendicarboxylate and the like may be employed.

[0054] For purposes of describing an exemplary manufacturing process employed to fabricate fuse 10, the layers of fuse 10 are referred to according to the following table:

Process Layer	Figure 2 Layer	Figure 2 Reference
1	Upper Outer Insulating Layer	26
2	Upper Intermediate Insulation Layer	22
3	Foil Fuse Element Layer	20
4	Lower Intermediate Insulating Layer	24
5	Lower Outer Insulating Layer	28

[0055] Using these designations, Figure 3 is a flow chart of an exemplary method 60 of manufacturing fuse 10 (shown in Figures 1 and 2). Foil fuse element layer 20 (layer 3) is laminated 62 to lower intermediate layer 24 (layer 4) according to known lamination techniques. Foil fuse element layer 20 (layer 3) is then etched 64 away into a desired shape upon lower intermediate insulating layer 24 (layer 4) using known techniques, including but not limited to use of a ferric chloride solution. In an exemplary embodiment, foil fuse element layer 20 (layer 3) is formed such that the capital I shaped foil fuse element remains as described above in relation to Figure 2 according to a known etching process. In alternative embodiments, die cutting operations may be employed in lieu of etching operations to form the fusible link 30 and contact pads 32, 34.

[0056] After forming 64 foil fuse element layer (layer 3) from lower intermediate insulating layer (layer 4) has been completed, upper intermediate insulating layer 22 (layer 2) is laminated 66 to pre-laminated foil fuse element layer 20 (layer 3) and lower intermediate insulating layer (layer 4) from step 62, according to known lamination techniques. A three layer lamination is thereby formed with foil fuse element layer 20 (layer 3) sandwiched between intermediate insulating layers 22, 24 (layers 2 and 4).

[0057] Termination openings 36, 38 and fusible link opening 40 (all shown in Figure 2) are then formed 68 in upper intermediate insulating layer 22 (layer 2) according to a known etching, punching, or drilling process. Fusible link opening

42 (shown in Figure 2) is also formed 68 in lower intermediate insulating layer 28 according to a known process, including but not limited to etching, punching and drilling. Fuse element layer contact pads 32, 34 (shown in Figure 2) are therefore exposed through termination openings 36, 38 in upper intermediate insulating layer 22 (layer 2). Fusible link 30 (shown in Figure 2) is exposed within fusible link openings 40, 42 of respective intermediate insulating layers 22, 24 (layers 2 and 4). In alternative embodiments, die cutting operations, drilling and punching operations, and the like may be employed in lieu of etching operations to form the fusible link opening 40 and termination openings 36, 38.

[0058] After forming 68 the openings or windows into intermediate insulation layers 22, 24 (layers 2 and 4), outer insulating layers 26, 28 (layers 1 and 5) are laminated 70 to the three layer combination (layers 2, 3, and 4) from steps 66 and 68. Outer insulation layers 26, 28 (layers 1 and 5) are laminated to the three layer combination using processes and techniques known in the art.

[0059] After outer insulation layers 26, 28 (layers 1 and 5) are laminated 70 to form a five layer combination, termination openings 46, 48 (shown in Figure 2) are formed 72, according to known methods and techniques into upper outer insulating layer 26 (layer 1) such that fuse element contact pads 32, 34 (shown in Figure 2) are exposed through upper outer insulation layer 26 (layer 1) and upper intermediate insulation layer 22 (layer 2) through respective termination openings 36, 38, and 46, 48. Lower outer insulating layer 28 (layer 5) is then marked 74 with indicia pertaining to operating characteristics of fuse 10 (shown in Figures 1 and 2), such as voltage or current ratings, a fuse classification code, etc. Marking 74 may be performed according to known processes, such as, for example, laser marking, chemical etching or plasma etching. It is appreciated that other known conductive contact pads, including but not limited to Nickel/Gold, Nickel/Tin, Nickel/Tin/Lead and Tin plated pads, may be employed in alternative embodiments in lieu of solder contacts 12.

[0060] Solder is then applied 76 to complete solder contacts 12 (shown in Figure 1) in conductive communication with fuse element contact pads 32,

34 (shown in Figure 2). Therefore, an electrical connection may be established through fusible link 30 (shown in Figure 2) when solder contacts 12 are coupled to line and load electrical connections of an energized circuit.

[0061] While fuses 10 could be manufactured singly according to the method thus far described, in an illustrative embodiment, fuses 10 are fabricated collectively in sheet form and then separated or singulated 78 into individual fuses 10. When formed in a batch process, various shapes and dimensions of fusible links 30 may be formed at the same time with precision control of etching and die cutting processes. In addition, roll to roll lamination processes may be employed in a continuous fabrication process to manufacture a large number of fuses with minimal time.

[0062] Further, fuses including additional layers may be fabricated without departing from the basic methodology described above. Thus, multiple fuse element layers may be utilized and/or additional insulating layers to fabricate fuses with different performance characteristics and various package sizes.

[0063] Fuses may therefore be efficiently formed using low cost, widely available materials in a batch process using inexpensive known techniques and processes. Photochemical etching processes allow rather precise formation of fusible link 30 and contact pads 32, 34 of thin fuse element layer 20, even for very small fuses, with uniform thickness and conductivity to minimize variation in final performance of fuses 10. Moreover, the use of thin metal foil materials to form fuse element layer 20 renders it possible to construct fuses of very low resistance in relation to known comparable fuses.

[0064] Figure 4 is an exploded perspective view of a second embodiment of a foil fuse 90 substantially similar to fuse 10 (described above in relation to Figures 1-3) except for the construction of lower intermediate insulating layer 24. Notably, fusible link opening 42 (shown in Figure 2) in lower intermediate insulating layer 24 is not present in fuse 90, and fusible link 30 extends directly across the surface of lower intermediate insulation layer 24. This particular construction is

satisfactory for fuse operation at intermediate temperatures in that fusible link opening 40 will inhibit or at least reduce heat transfer from fusible link 30 to intermediate insulating layers 22, 24. Resistance of fuse 90 is accordingly reduced during fuse operation, and fusible link opening 40 in upper intermediate insulating layer 40 inhibits arc tracking and facilitates full clearing of the circuit through the fuse.

[0065] Fuse 90 is constructed in substantial accordance with method 60 (described above in relation to Figure 3) except, of course, that fusible link opening 42 (shown in Figure 2) in lower intermediate insulation layer 24 is not formed.

[0066] Figure 5 is an exploded perspective view of a third embodiment of a foil fuse 100 substantially similar to fuse 90 (described above in relation to Figure 4) except for the construction of upper intermediate insulating layer 22. Notably, fusible link opening 40 (shown in Figure 2) in upper intermediate insulating layer 22 is not present in fuse 100, and fusible link 30 extends directly across the surface of both upper and lower intermediate insulation layers 22, 24.

[0067] Fuse 100 is constructed in substantial accordance with method 60 (described above in relation to Figure 3) except, of course, that fusible link openings 40 and 42 (shown in Figure 2) in intermediate insulating layers 22, 24 are not formed.

[0068] It is appreciated that thin ceramic substrates may be employed in any of the foregoing embodiments in lieu of polymer films, but may be especially advisable with fuse 100 to ensure proper operation of the fuse. For example, low temperature cofireable ceramic materials and the like may be employed in alternative embodiments of the present invention.

[0069] Using the above-described etching and die cutting processes on thin metallized foil materials for forming fusible links, a variety of differently shaped metal foil fuse links may be formed to meet particular performance objectives. For example, Figures 6-10 illustrate a plurality of fuse element geometries, together with exemplary dimensions, that may be employed in fuse 10 (shown in Figures 1 and

2), fuse 90 (shown in Figure 4) and fuse 100 (shown in Figure 5). It is recognized, however, that the fuse link geometry described and illustrated herein are for illustrative purposes only and in no way are intended to limit practice of the invention to any particular foil shape or fusible link configuration.

[0070] Figure 11 is an exploded perspective view of a fourth embodiment of a fuse 120. Like the fuses described above, fuse 120 provides a low resistance fuse of a layered construction that is illustrated in Figure 11. Specifically, in an exemplary embodiment, fuse 120 is constructed essentially from five layers including foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124.

[0071] In accord with the foregoing embodiments fuse element 20 is an electro deposited, 3-5 micron thick copper foil applied to lower intermediate layer 24 according to known techniques. Thin fuse element layer 20 is formed in the shape of a capital I with a narrowed fusible link 30 extending between rectangular contact pads 32, 34, and is dimensioned to open when current flowing through fusible link 30 is less than about 7 ampere. It is contemplated, however, that various dimensions of the fusible link may be employed and that thin fuse element layer 20 may be formed from various metal foil materials and alloys in lieu of a copper foil.

[0072] Upper intermediate insulating layer 22 overlies foil fuse element layer 20 and includes a circular shaped fusible link opening 40 extending therethrough and overlying fusible link 30 of foil fuse element layer 20. In contrast to the fuses 10, 90, and 100 described above, upper intermediate insulating layer 22 in fuse 120 does not include termination openings 36, 38 (shown in Figures 2-5) but rather is solid everywhere except for fusible link opening 40.

[0073] Lower intermediate insulating layer 24 underlies foil fuse element layer 20 and includes a circular shaped fuse link opening 42 underlying fusible link 30 of foil fuse element layer 20. As such, fusible link 30 extends across respective fuse link openings 40, 42 in upper and lower intermediate insulating layers

22, 24 such that fusible link 30 contacts a surface of neither intermediate insulating layer 22, 24 as fusible link 30 extends between contact pads 32, 34 of foil fuse element 20. In other words, when fuse 10 is fully fabricated, fusible link 30 is effectively suspended in an air pocket by virtue of fuse link openings 40, 42 in respective intermediate insulating layers 22, 24.

[0074] As such, fuse link openings 40, 42 prevent heat transfer to intermediate insulating layers 22, 24 that in conventional fuses contributes to increased electrical resistance of the fuse. Fuse 120 therefore operates at a lower resistance than known fuses and consequently is less of a circuit perturbation than known comparable fuses. In addition, and unlike known fuses, the air pocket created by fusible link openings 40, 42 inhibits arc tracking and facilitates complete clearing of the circuit through fusible link 30. Still further, the air pocket provides for venting of gases therein when the fusible link operates and alleviates undesirable gas buildup and pressure internal to the fuse.

[0075] As noted above, upper and lower intermediate insulation layers are each fabricated from a dielectric film in an illustrative embodiment, such as a 0.002 inch thick polyimide film commercially available and sold under the mark KAPTON® from E. I. du Pont de Nemours and Company of Wilmington, Delaware. In alternative embodiments, other suitable electrical insulation materials such as CIRLEX® adhesiveless polyimide lamination materials, Pyrolux, polyethylene naphthalendicarboxylate (sometimes referred to as PEN) Zyvrex liquid crystal polymer material commercially available from Rogers Corporation, and the like may be employed.

[0076] Upper outer insulation layer 26 overlies upper intermediate layer 22 and includes a continuous surface 50 extending over upper outer insulating layer 26 and overlying fusible link opening 40 of upper intermediate insulating layer 22, thereby enclosing and adequately insulating fusible link 30. Notably, and as illustrated in Figure 11, upper intermediate layer 122 does not include termination openings 46, 48 (shown in Figures 2-5).

[0077] In a further embodiment, upper outer insulation layer 122 and/or lower outer insulation layer 124 is fabricated from translucent or transparent materials that facilitate visual indication of an opened fuse within fusible link openings 40, 42.

[0078] Lower outer insulating layer 124 underlies lower intermediate insulating layer 24 and is solid, i.e., has no openings. The continuous solid surface of lower outer insulating layer 24 therefore adequately insulates fusible link 30 beneath fusible link opening 42 of lower intermediate insulating layer 28.

[0079] In an illustrative embodiment, upper and lower outer insulation layers are each fabricated from a dielectric film, such as a 0.005 inch thick polyimide film commercially available and sold under the mark KAPTON® from E. I. du Pont de Nemours and Company of Wilmington, Delaware. It is appreciated, however, that in alternative embodiments, other suitable electrical insulation materials such as CIRLEX® adhesiveless polyimide lamination materials, Pyrolux, polyethylene naphthalendicarboxylate and the like may be employed.

[0080] Unlike the foregoing embodiments of fuses illustrated in Figures 2-5 that include solder bump terminations, upper outer insulating layer 122 and lower outer insulating layer 124 each include elongated termination slots 126, 128 formed into each lateral side thereof and extending above and below fuse link contact pads 32, 34. When the layers of the fuse are assembled, slots 126, 128 are metallized on a vertical face thereof to form a contact termination on each lateral end of fuse 120, together with metallized vertical lateral faces 130, 132 of upper intermediate insulating layer and lower intermediate insulating layers 22, 24, and metallized strips 134, 136 extending on the outer surfaces of upper and lower outer insulating layers 122, 124, respectively. Fuse 120 may therefore be surface mounted to a printed circuit board while establishing electrical connection to the fuse element contact pads 32, 34.

[0081] For purposes of describing an exemplary manufacturing process employed to fabricate fuse 120, the layers of fuse 120 are referred to according to the following table:

Process Layer	Figure 11 Layer	Figure 11 Reference
1	Upper Outer Insulating Layer	122
2	Upper Intermediate Insulation Layer	22
3	Foil Fuse Element Layer	20
4	Lower Intermediate Insulating Layer	24
5	Lower Outer Insulating Layer	124

[0082] Using these designations, Figure 12 is a flow chart of an exemplary method 150 of manufacturing fuse 120 (shown in Figure 11). Foil fuse element layer 20 (layer 3) is laminated 152 to lower intermediate layer 24 (layer 4) according to known lamination techniques to form a metallized construction. Foil fuse element layer 20 (layer 3) is then formed 154 into a desired shape upon lower intermediate insulating layer 24 (layer 4) using known techniques, including but not limited to use of a ferric chloride solution etching process. In an exemplary embodiment, foil fuse element layer 20 (layer 3) is formed such that the capital I shaped foil fuse element remains as described above. In alternative embodiments, die cutting operations may be employed in lieu of etching operations to form the fusible link 30 contact pads 32, 34. It is understood that a variety of shapes of fusible elements may be employed in further and/or alternative embodiments of the invention, including but not limited to those illustrated in Figures 6-10. It is further contemplated that in further and/or alternative embodiments the fuse element layer may be metallized and formed using a sputtering process, a plating process, a screen printing process, and the like as those in the art will appreciated.

[0083] After forming 154 foil fuse element layer (layer 3) from lower intermediate insulating layer (layer 4) has been completed, upper intermediate insulating layer 22 (layer 2) is laminated 156 to pre-laminated foil fuse element layer 20 (layer 3) and lower intermediate insulating layer 24 (layer 4) from step 152, according to known lamination techniques. A three layer lamination is thereby

formed with foil fuse element layer 20 (layer 3) sandwiched between intermediate insulating layers 22, 24 (layers 2 and 4).

[0084] Fusible link openings 40 (shown in Figure 11) are then formed 158 in upper intermediate insulating layer 22 (layer 2) and fusible link opening 42 (shown in Figure 11) is formed 158 in lower intermediate insulating layer 28. Fusible link 30 (shown in Figure 11) is exposed within fusible link openings 40, 42 of respective intermediate insulating layers 22, 24 (layers 2 and 4). In exemplary embodiments, opening 40 are formed according to known etching, punching, drilling and die cutting operations to form fusible link openings 40 and 42.

[0085] After etching 158 the openings into intermediate insulation layers 22, 24 (layers 2 and 4), outer insulating layers 122, 124 (layers 1 and 5) are laminated 160 to the three layer combination (layers 2, 3, and 4) from steps 156 and 158. Outer insulation layers 122, 124 (layers 1 and 5) are laminated 160 to the three layer combination using processes and techniques known in the art.

[0086] One form of lamination that may be particularly advantageous for purposed of the present invention employs the use of no-flow polyimide prepreg materials such as those available from Arlon Materials for Electronics of Bear, Delaware. Such materials have expansion characteristics below those of acrylic adhesives which reduces probability of through-hole failures, as well as better endures thermal cycling without delaminating than other lamination bonding agents. It is appreciated, however, that bonding agent requirements may vary depending upon the characteristics of the fuse being manufactured, and therefore that lamination bonding agents that may be unsuitable for one type of fuse or fuse rating may be acceptable for another type of fuse or fuse rating.

[0087] Unlike outer insulating layers 26, 28 (shown in Figure 2), outer insulating layers 122, 124 (shown in Figure 11) are metallized with a copper foil on an outer surface thereof opposite the intermediate insulating layers. In an illustrative embodiment, this may be achieved with CIRLEX® polyimide technology including a polyimide sheet laminated with a copper foil without adhesives that may

compromise proper operation of the fuse. In another exemplary embodiment, this may be achieved with Espanex polyimide sheet materials laminated with a sputtered metal film without adhesives. It is contemplated that other conductive materials and alloys may be employed in lieu of copper foil for this purpose, and further that outer insulating layers 122, 124 may be metallized by other processes and techniques in lieu of CIRLEX® materials in alternative embodiments.

[0088] After outer insulation layers 26, 28 (layers 1 and 5) are laminated 160 to form a five layer combination, elongated through holes corresponding to slots 126, 128 are formed 164 through the five layer combination formed in step 160. In various embodiments, slots 126, 128 are laser machined, chemically etched, plasma etched, punched or drilled as they are formed 164. Slot termination strips 134, 126 (shown in Figure 11) are then formed 166 on the metallized outer surfaces of outer insulation layers 122, 124 through an etching process, and fuse element layer 20 is etched 166 to expose fuse element layer contact pads 32, 34 (shown in Figure 11) within termination slots 126, 128. After etching 166 the layered combination to form termination strips 134, 136 and etching fuse element layer 20 to expose fuse element layer contact pads 32, 34, the termination slots 126, 128 are metallized 168 according to a plating process to complete the metallized contact terminations in slots 126, 128. In exemplary embodiments, Nickel/Gold, Nickel/Tin, Nickel/Tin/Lead and Tin may be employed in known plating processes to complete terminations in slots 126, 128. As such, fuses 120 may be fabricated that are particularly suited for surface mounting to, for example, a printed circuit board, although in other applications other connection schemes may be used in lieu of surface of mounting.

[0089] In an alternative embodiment, castellated contact terminations including cylindrical through-holes may be employed in lieu of the above through-hole metallization in slots 126, 128.

[0090] Once the contact terminations in slots 126, 128 are competed, lower outer insulating layer 124 (layer 5) is then marked 170 with indicia pertaining to operating characteristics of fuse 120 (shown in Figure 120), such as voltage or current

ratings, a fuse classification code, etc. Marking 170 may be performed according to known processes, such as, for example, laser marking, chemical etching, or plasma etching.

[0091] While fuses 120 could be manufactured singly according to the method thus far described, in an illustrative embodiment, fuses 120 are fabricated collectively in sheet form and then separated or singulated 172 into individual fuses 120. When formed in a batch process, various shapes and dimensions of fusible links 30 (shown in Figure 11) may be formed at the same time with precision control of etching and die cutting processes. In addition, roll to roll lamination processes may be employed in a continuous fabrication process to manufacture a large number of fuses with minimal time. Further additional fuse element layers and/or insulating layers may be employed to provide fuses of increased fuse ratings and physical size.

[0092] Once the manufacture is completed, an electrical connection may be established through fusible link 30 (shown in Figure 11) when the contact terminations are coupled to line and load electrical connections of an energized circuit.

[0093] It is recognized that fuse 120 may be further modified as described above in Figures 4 and 5 by elimination one or both of fusible link openings 40, 42 in intermediate insulation layers 22, 24. The resistance of fuse 120 may accordingly be varied for different applications and different operating temperatures of fuse 120.

[0094] In a further embodiment, one or both of outer insulating layers 122, 124 may be fabricated from a translucent material to provide local fuse state indication through the outer insulating layers 122, 124. Thus, when fusible link 30 operates, fuse 120 may be readily identified for replacement, which can be particularly advantageous when a large number of fuses are employed in an electrical system.

[0095] According to the above-described methodology, fuses may therefore be efficiently formed using low cost, widely available materials in a batch

process using inexpensive known techniques and processes. Photochemical etching processes allow rather precise formation of fusible link 30 and contact pads 32, 34 of thin fuse element layer 20, even for very small fuses, with uniform thickness and conductivity to minimize variation in final performance of fuses 10. Moreover, the use of thin metal foil materials to form fuse element layer 20 renders it possible to construct fuses of very low resistance in relation to known comparable fuses.

[0096] Figures 13 and 14 are perspective and exploded views, respectively, of a fifth embodiment of a fuse 200 formed in accordance with an exemplary aspect of the invention. Like the fuses described above, fuse 200 provides a low resistance fuse of a layered construction. Fuse 200 is constructed substantially similar to the fuse 120 (shown in Figure 11) except as noted below, and like reference characters of fuse 120 are indicated with like reference characters in Figures 13 and 14.

[0097] In an exemplary embodiment, fuse 200 includes foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124. The fuse element layer 20, and the layers 22, 24, 122 and 124 are fabricated and assembled as described above in relation to Figures 11 and 12.

[0098] Unlike the foregoing embodiments wherein the fuse element layer 20 is either suspended in the vicinity of fusible link openings 40 and 42 or in direct contact with the upper or lower intermediate insulating layers 22 and 24, the fuse element layer 20 is supported on a polymer membrane 202. The polymer membrane 202 serves to support the fuse element 20 and provide a surface on which to form the fuse element layer 20. In operation, the metal fusible link 30 of the fuse element layer 20 melts and clears the circuit through the fuse 200 without carbonizing the polymer membrane 202 or arc tracking on the surface of the membrane 202.

[0099] Certain geometries and lengths of fusible links in the fuse element layer 20 render the polymer membrane 202 especially advisable. For example, when a serpentine or notched link in the fuse element layer 20 is employed,

the polymer membrane 202 supports the fusible link so that the fuse element layer 20 does not touch a surface of the fusible link openings 40 and 42 located above and below the fusible link prior to clearing the circuit. For higher voltage fuses and/or time delay fuse elements having fusible elements of increased length, and when fusible links of multiple shapes and/or geometries are employed, the polymer membrane 202 is believed to play a significant role in obtaining acceptable fuse operation. In the design of long element, time delay fuses, the fuse element layer 20 expands during overload conditions in accordance with the associated coefficient of thermal expansion of the metal used to form the fuse element layer 20. Thermal heating of the fuse element layer 20 continues until at least a portion of the fuse element layer 20 melts to a liquid state. Thermal dissipation through the polymer membrane 202 during the thermal heating of the fuse element layer 20 may result in a substantial, and also desirable, change in time/current characteristics of the fuse 200.

[00100] The polymer membrane 202 further provides additional structural benefits in the fuse 200. For example, the polymer membrane 202 provides structural strength to the fusible link by supporting the fuse element layer 20 during the manufacturing process, thereby stiffening the fusible link to avoid potential fracturing during sequential lamination processes at high temperature and pressure. Additionally, the polymer membrane 202 strengthens the fuse element layer to avoid potential fracturing of the fusible link as the fuse is handled and installed. Still further, the polymer membrane 202 reduces a likelihood of fracture of the fusible link due to thermal stresses during current cycling in use, which causes thermal expansion and contraction of the fuse element layer. Fatiguing of the fusible link to failure due to current cycling is therefore mitigated due to the structural strength of the polymer membrane 202.

[00101] Thus, by incorporating the polymer membrane 202 or other support structure for the fuse element layer 20, the fuse 200 enjoys improved mechanical shock, thermal shock, impact resistance, vibration endurance and perhaps even superior performance in relation to, for example, the fuse 120 (shown in Figure 11) wherein the fusible link 30 is suspended in air.

[00102] While it is appreciated that the polymer membrane 202 is desirable for certain types or applications of fuses as noted above, in fast acting fuses and fuses having comparatively shorter fusible links, the fusible links may have sufficient structural integrity and acceptable performance to render the polymer membrane 202 optional. In short fusible link and fast acting fuses, the provision of the polymer membrane 202 is unlikely to have a substantial effect on the time/current characteristics of the fuse 200.

[00103] In an exemplary embodiment, the polymer membrane 202 is a thin membrane having a thickness of about .0005 inches or less, although it is appreciated that greater thicknesses of membranes may be used in alternative embodiments. A thin polymer membrane ideally melts, vaporizes or otherwise disintegrates during fuse operation. Exemplary materials for the polymer membrane 202 include but are not limited to Liquid Crystal Polymer (LCP) materials and polyimide film materials such as those described above. A liquid polyimide material may also be utilized to form a support membrane 202 for the fuse element layer 20 according to a known process or technique, including but not limited to spin coat operations or application with a doctor blade. The polymer membrane 202 may be formed into a variety of shapes as desired or as necessary to construct a fuse having particular fusing characteristic.

[00104] Fuse 200 may be manufactured according to the method 150 shown in Figure 12 with appropriate modification to form the fuse element layer 20 upon or otherwise support the fuse element layer 20 with the polymer membrane 202.

[00105] Figure 15 is an exploded view of a sixth embodiment of a fuse 210 formed in accordance with an exemplary aspect of the invention. Like the fuses described above, fuse 210 provides a low resistance fuse of a layered construction. Fuse 210 is constructed substantially similar to the fuse 120 (shown in Figure 11) except as noted below, and like reference characters of fuse 120 are indicated with like reference characters in Figure 15.

[00106] In an exemplary embodiment, fuse 210 includes foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124. The fuse element layer 20, and the layers 22, 24, 122 and 124 are fabricated and assembled as described above in relation to Figures 11 and 12.

[00107] Unlike the foregoing embodiments, arc quenching media 212 is provided within the fusible link openings 40 and 42 of the upper or lower intermediate insulating layers 22 and 24. Dissipation of arc energy as the fuse element layer 20 opens is therefore facilitated, which is beneficial as the voltage rating of the fuse is increased. If arc energy were to rupture the fuse and escape to the ambient environment, sensitive electrical equipment and electronic components associated with the fuse may be jeopardized and hazardous conditions for nearby people and personnel may result. When arcing occurs, the surrounding arc quenching media 212 heats and undergoes a phase transition, and arcing energy is absorbed by the arc quenching media due to entropy. Arc energy is therefore effectively contained within the confines of the fusible link openings 40 and 42 at a location interior to the fuse 210. Damage to electrical equipment and components is therefore avoided, and a safe operating environment is preserved.

[00108] By way of example, ceramic, silicone and ceramic/silicone composite materials known to have arc-suppressing characteristics may be employed as the arc quenching media 212. As those in the art may appreciate, ceramic products in powder, slurry or adhesive form may be used and applied to the fuse link openings 40 and 42 according to known processes and techniques. More specifically, silicones, such as RTV, and modified alkoxy silicone may be used as arc quenching media 212. Ceramic materials such as such as Alumina ($A1_2 0_3$), Silica (SiO_2), Magnesium Oxide (MgO), Alumina Trihydrate ($Al_2O_3*3H_20$) and/or any compound within the $Al_2O_3*MgO*SiO_2$ terinary system may likewise be used as arc quenching media 212. $MgO*ZrO_2$ compound and spinels such as Al_2O_3*MgO, and other arc quenching media with high heat of transformation, such as sodium nitrate ($NaNO_2$, $NaNO_3$) are also suitable for use as arc quenching media 210.

[00109] As illustrated in Figure 15, one or more additional layers of insulating material 214 may be provided proximate the fuse element layer 20, and a fusible link opening 216 may be provided therein. The insulating layer 214 may be fabricated from the same or similar materials as upper and lower insulating layers 22 and 24 described above. Arc quenching media 212 fills the opening 216 in the insulation layer 214. Additional insulation and arc quenching capability is therefore provided to achieve desired fusing characteristics for higher voltage fuses.

[00110] It is understood that the polymer membrane 202 (shown in Figure 14) may be employed in combination with the fuse 210 as desired. It is also understood that fuse 210 may be manufactured according to the method 150 shown in Figure 12 with appropriate modification to incorporate the arc quenching media 212 and one or more additional insulation layers 214.

[00111] Figure 16 is an exploded view of a seventh embodiment of a fuse 220 formed in accordance with an exemplary aspect of the invention. Like the fuses described above, fuse 220 provides a low resistance fuse of a layered construction. As fuse 220 includes common elements with fuse 120 (shown in Figure 11), like reference characters of fuse 120 are indicated with like reference characters in Figure 16.

[00112] In an exemplary embodiment, fuse 220 includes foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124. The fuse element layer 20, and the layers 22, 24, 122 and 124 are described above in relation to Figures 11 and 12.

[00113] Unlike the foregoing embodiments which are adhesiveless, the fuse 220 includes adhesive elements 222 (shown in phantom in Figure 16) securing the fuse element layer 20 to the upper and lower intermediate insulating layers 22 and 24, and also to secure the upper and lower intermediate insulating layers 22 and 24 to the outer insulating layers 122 and 124. Unlike conventional adhesives, the adhesive elements 222 in an illustrative embodiment do not carbonize or arc track

as the fuse element layer 20 opens and clears a circuit through the fuse 220. Additionally, the adhesive elements 222 allow for lower lamination temperature and pressure during manufacturing of the fuse 220, whereas the above-described adhesiveless embodiments require comparatively higher lamination temperature and pressure. Reduced lamination temperatures and pressure in manufacturing the fuse 220 provides a number of benefits, including but not limited to reduced energy consumption in producing fuses 220 and simplified manufacturing procedures, each of which reduces costs of providing fuses 220.

[00114] In various embodiments, the adhesive elements 222 may be, for example, a polyimide liquid adhesive, a polyimide adhesive film or a silicon adhesive More specifically, materials such as Espanex SPI and Espanex SPC bonded films may be used. Alternatively, a liquid polymer may be screen printed or cast then cured to form an adhesive element 222.

[00115] When adhesive films are employed as adhesive elements 222, the adhesive film may be pre-punched to form the fusible link openings 40 and 42 in the upper and lower intermediate insulating layers 22 and 24. Once the openings 40 and 42 are formed, the adhesive elements 222 are laminated to the respective intermediate insulating layers 22 and 24, and the outer layers 122 and 124. Polyimide precursors in the form of overlay film and inks may be employed in the lamination process, and once cured, all of the electrical, mechanical and dimensional properties of polyimide are in place, together with the benefits of polyimide as described in detail above.

[00116] In a further embodiment, adhesive elements 222 may encapsulate the metal foil fuse element layer 20. A lower cure temperature encapsulant may be used, for example, when either a lower melt temperature fusing alloy or metal is used, or when a Metcalf type alloying system is used.

[00117] While four adhesive elements 222 are shown in Figure 16, it is appreciated that greater or fewer numbers of adhesive elements 222 may be

employed in alternative embodiments while obtaining at least some of the benefits of the fuse 220 and without departing from the scope of the present invention.

[00118] It is understood that the polymer membrane 202 (shown in Figure 14) may be employed in combination with the fuse 220 as desired. It is also understood that fuse 220 may be manufactured according to the method 150 shown in Figure 12 with appropriate modification to incorporate the adhesive elements 222. Additionally, it is understood that arc quenching media 212 (shown in Figure 15) and one or more additional insulation layers 214 (also shown in Figure 15) may be employed in fuse 220 as desired.

[00119] Figure 17 is a schematic view of an eighth embodiment of a fuse 230 formed in accordance with an exemplary aspect of the invention. Like the fuses described above, fuse 230 provides a low resistance fuse of a layered construction. As fuse 230 includes common elements with the foregoing embodiments, like reference characters of fuse 230 are indicated with like reference characters in Figure 17.

[00120] In an exemplary embodiment, fuse 230 includes foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124. The fuse element layer 20, and the layers 22, 24, 122 and 124 are described above in relation to Figures 11 and 12.

[00121] Unlike the foregoing embodiments, fuse 230 includes a heat sink 232 and an additional insulating layer 214 (also shown in Figure 15). The thermal heat sink 232 is placed in close proximity to the fusible link 30 of the fuse element layer 20, and the heat sink 232 improves time delay characteristics for certain fuse applications. As localized heating typically occurs in the center of the fuse element layer 20 (i.e., at the location of the fusible link 30 shown in Figure 17), the heat sink 232 directs heat away from the fuse element layer 20 as current flows therethrough. Consequently, an increased period of time is required to heat the fuse

element layer 20 to its melting point to open or operate the fuse 230 at a specified current overload condition.

[00122] In an exemplary embodiment, the heat sink 232 is a ceramic or metal element located in close proximity to the fuse element, either above or below the fuse element layer 20, although it is appreciated that other heat sink materials and relative positions of the heat sink 232 may be employed in other embodiments. In one embodiment, and as shown in Figure 17, the heat sink 232 is positioned away from the warmest portion of the fuse element layer 20 in operation. That is, the heat sink 232 is positioned away from or spaced from the center of the element layer 20 or the fusible link 30 in the illustrated embodiment in Figure 17. By spacing the heat sink 232 from the fusible link 30, the heat sink 231 does not interfere with opening and clearing of the circuit through the fuse element layer 20.

[00123] It is understood that the polymer membrane 202 (shown in Figure 14) may be employed in combination with the fuse 220 as desired. Additionally, it is understood that arc quenching media 212 (shown in Figure 15) and one or more additional insulation layers 214 (also shown in Figure 15) may be employed in fuse 230 as desired. Adhesive elements 222 (shown in Figure 16) may likewise be employed in fuse 230. It is also understood that fuse 220 may be manufactured according to the method 150 shown in Figure 12 with appropriate modification to incorporate the aforementioned features.

[00124] Figure 18 is a top plan view of one exemplary embodiment of a fuse element layer 20 which may be used with any of the foregoing fuse embodiments. As shown in Figure 18, the fuse element 20 includes heater elements 240. Especially when lower melt temperature materials are used to form the fuse element layer 20, addition of the heater elements 240 may facilitate a fuse with fast acting and high surge withstanding characteristics. Typically a fuse with very fast acting characteristics is not able to withstand inrush currents experienced in, for example, applications such as LCD flat panel displays. The heater elements 240 allow the fuse element layer 20 to withstand such inrush currents without opening of the fuse.

[00125] In an exemplary embodiment, heater alloys such as Nickel, Balco, Platinum, Kanthal or Nichrome may be used as heater elements 240 and applied to the fuse element layer 20 according to known processes and techniques. These and other alternative materials and metals may be selected for the heater elements 240 based upon material properties such as bulk resistivity, Temperature Coefficient of Resistance (TCR), stability, linearity and cost.

[00126] While two heater elements 240 are illustrated on a particular fuse element layer 20 in the shape of a capital I in Figure 18, it is appreciated that the fuse element layer may be formed in a variety of geometric shapes, including but not limited to the shapes shown in Figures 6-10 without departing from the scope of the instant invention, and that greater or fewer heater elements 240 may be employed to suit different fuse element geometries or to achieve applicable specifications for particular performance parameters.

[00127] Figure 19 is a top plan view of an exemplary embodiment of a portion of a fuse element layer 250 formed on an insulating layer 252. The fuse element layer 250 is formed as described in relation to fuse element layer 20 as set forth above into a serpentine geometry reminiscent of that shown in Figure 10. The insulating layer 252 is formed as described in relation to lower intermediate insulation layer 24 as set forth above. The fuse element layer may be used in any of the foregoing fuse embodiments, and may be used in combination with any selected feature noted above in Figures 14-18 (i.e., the polymer membrane 202, the arc quenching media 212, the adhesive elements 222, the heat sink 232, or the heaters 240).

[00128] A fusible link 254 extends across a fusible link opening 256 formed in the insulating layer 252, and the fusible link has a reduced width in comparison to the remainder of the serpentine fuse element layer 250. The serpentine fuse element layer 250 and the fusible link 254 establish a relatively long conductive path on the insulating layer 252 and is well suited for a time delay fuse.

[00129] As those in the art may appreciate, a melting point of the fuse element layer 250 in time may determined by calculating a maximum energy absorption capacity (Q) of the fuse element layer 250. More specifically, the maximum energy absorption capacity be calculated according to the following relationship:

$$Q = \int i^2 R dt = C_p \Delta T \delta v = C_p \Delta T \delta A l \qquad (5)$$

where v is the volume of the material of the formed fuse element layer geometry, i is an instantaneous current value flowing through the fuse element, t is the time value for current flowing through the fuse element, ΔT is the difference between the melting temperature of the material used to form the fuse element layer and an ambient temperature of the material at time t, C_p is the specific heat capacity of the fuse element layer material, δ is the density of the fuse element layer material, A is the cross sectional area of the fuse element, and L is the length of the fuse element.

[00130] The cross-sectional area, length and type of the material used for the fuse element layer will affect the resistance (R) thereof according to the relationship:

$$R = {\rho l}/{A} \qquad (6)$$

where ρ is the material resistivity of the fuse element layer, l is the length of the fuse element, and A is the cross sectional area of the fuse element.

[00131] Considering Equations (4) and (5), a fuse element layer may be designed with an appropriate cross sectional area and length to provided specified fusing characteristics at or below a predetermined electrical resistance for the fuse. Low resistance fuses may therefore be constructed to meet or exceed specific objectives.

[00132] For example, one or more heater elements 240 (shown in Figure 18) in series with a fuse element layer 250 fabricated from a low vaporization temperature alloy in combination with fusible link openings 256 in insulating layers

positioned both above and below the fuse element layer 250, optimal adiabatic conditions are created for fuse operation.

[00133] Ideal fusing conditions are adiabatic, where there is no gain or loss of heat during a current overload condition. In an adiabatic condition, the circuit is cleared without the exchange of heat with surrounding elements. Realistically, adiabatic conditions occur only during very fast opening events wherein there is little or no time for heat to dissipate either from the terminations of the fuse or the layers of the fuse. Consistent approximate adiabatic conditions may be realized, however, by modeling an adiabatic envelope around the fusible link, thereby enclosing the fusible link in a thermodynamic system in which here is no gain or loss of heat.

[00134] An adiabatic model envelope may be achieved at least in part by surrounding the fusible link with a material of low thermal conductivity. For example, an air pocket surrounding the fusing element via fusible link openings in the upper and lower insulating layers on either side of the fuse element layer will insulate the fusible link and prevent heat dissipation through the layers of the fuse. Additionally, constructing the fuse element geometry with a minimum aspect ratio, or element width divided by element thickness, reduces a surface area of the fuse element layer for heat transfer to, for example, the upper and lower intermediate insulating layers. Still further, placing a heater element, such as heater element 240 described above, in series with the fusing element prevents heat transfer from the fuse element to the layers of the fuse and to the fuse terminations.

[00135] By modeling an adiabatic envelope as described above, Joule heat will not be absorbed upon the occurrence of an over current and the fuse element can be melted away quickly. Even if after the fuse element has been melted away an arc is generated, the metallic vapor which likely generates the arc will be confined in the envelope.

[00136] For the foregoing embodiments of fuses, electrical characteristics of the fuse may be predicted by considering the thermal diffusivity of the fuse matrix in combination with the maximum energy absorption capacity of the

fuse element as described above. Thermal Diffusivity in the Heat Conduction Equation is the constant

$$\frac{\delta T(r,t)}{\delta t} = K\Delta^2(r,t) \tag{7}$$

which describes the rate at which heat is conducted through a medium, and is related to thermal conductivity k, specific heat C_p and density ρ by the relationship:

$$K = I_{mfpv=k\,/\,\rho C_p} \tag{8}$$

[00137] Figure 20 is an exploded view of a fuse manufacture 260 formed in accordance with an exemplary aspect of the invention. Like the fuses described above, the fuse manufacture 260 provides a low resistance fuse of a layered construction. As the manufacture 260 includes common elements with the foregoing embodiments, like reference characters are indicated with like reference characters in Figure 17.

[00138] In an exemplary embodiment, the fuse manufacture 260 includes foil fuse element layer 20 sandwiched between upper and lower intermediate insulating layers 22, 24 which, in turn, are sandwiched between upper and lower outer insulation layers 122, 124. The fuse element layer 20, and the layers 22, 24, 122 and 124 are described above in relation to Figures 11 and 12. An additional insulation layer 214 is also provided as described above in relation to Figure 15.

[00139] Unlike the foregoing embodiments, a mask 262 is provided to facilitate formation of one or more of the layers. The mask 262 defines an opening 264 corresponding to a fusible link opening in one of the layers, and rounded termination grooves 266 for shaping the respective layer. The mask 262 is employed to facilitate formation of the fusible link openings and the terminations of the respective layers of the fuse during manufacturing processes. In an exemplary embodiment the mask 262 is a copper foil mask used with a plasma etching process, although it is contemplated that other materials and other techniques may be employed as desired to form and shape the openings and terminations of the layers of the fuse.

[00140] In an exemplary embodiment, the mask 262 is physically removed from the construction prior to laminating the layers of the fuse together. In another embodiment, the mask may be incorporated into a layer in the final fuse product.

[00141] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.